

# RELATIONSHIP OF OXYGEN AND OZONE ON GANYMEDE: OBSERVATIONAL AND THEORETICAL CONSTRAINTS

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The identification of oxygen [1,2] and ozone [3] on Ganymede has spurred a great deal of interest and excitement. Subsequent articles have discussed these "atmospheres" within the surface ice as radiation products [4,5], or the possibility of an oxygen ice "haze" [6].

Recent results from Galileo have shown that Ganymede has an intrinsic magnetic field [7], an atmosphere of atomic hydrogen [8], and that the ozone absorption features appear to be concentrated near the polar regions [9]. Recent observations from the Hubble Space Telescope suggest the presence of singlet oxygen emission in the polar regions [10] which Hall et al. have interpreted as auroral emission associated with the magnetic field. Spencer and Calvin [11] find, in contrast, that the visible spectral signature associated with molecular oxygen is concentrated in the equatorial regions, so there appears to be a competition between the two molecules, or at least a variation in the preferred stable form which may depend on temperature, latitude, composition, surface age, or all of these.

## Summary of HST Results:

In July of 1995 we obtained visible spectral data for a single pole-to-pole latitudinal strip on Ganymede, along with several Wide Field Planetary Camera images in three narrow band visible filters. To briefly summarize the results presented by Calvin and Spencer [11], the observations suggest that the recently identified volatile molecule oxygen is predominantly found in equatorial and northern mid-latitudes on the trailing hemisphere of the satellite. The spectroscopic absorption feature appears in both bright and dark terrains, but is weaker in dark regions consistent with the smaller mean photon path length in the surface in darker areas. Therefore the abundance of oxygen appears more dependent on latitude and longitude constraints than surface albedo. In high latitudes, where the spectra have strong upturns toward the blue, the oxygen band does not appear. This is the only apparent relationship to surface composition. The equatorial nature of the feature supports the

production of  $O_2$  through plasma bombardment and favors defect trapping as the location of the  $O_2$ . Figure 1 shows the Faint Object Spectrograph (FOS) data with model fits to the oxygen band depth using recently acquired transmission spectra of pure liquid oxygen [12].

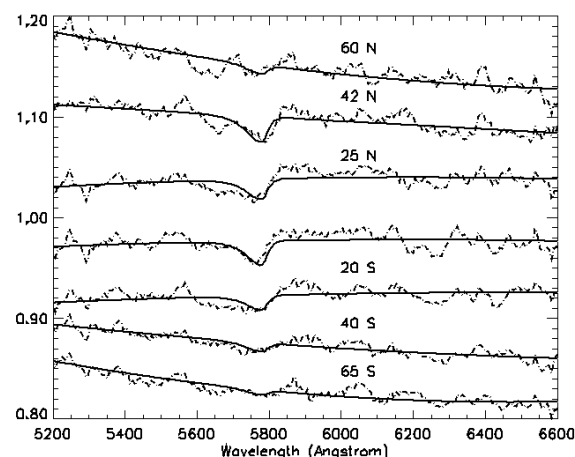


Figure 1. FOS spectra compared with model fits using liquid oxygen.

## Spectral Characteristics compared to pure $O_2$ :

Figure 1 suggests that in addition to variations in band strength with latitude there may be subtle changes in the position of the oxygen feature. The hemispherically averaged spectrum of Spencer et al. [2] and the equatorial spectrum in Figure 1 are shifted to slightly shorter wavelengths than in pure liquid oxygen (Figure 2). The other strong features at 20S, 25N, and 42N possibly have different shifts. Increasing latitude seems to be related to a longer wave-length for the center of the strongest  $O_2$  feature. At the equator the central wavelength is less than in pure liquid  $O_2$ , at 20S and 25 N the features have the same center, and at 42 N the center wavelength is longer than in liquid  $O_2$ . Given the high noise level this possibility needs to be confirmed in subsequent observations. If real, this trend may suggest a temperature dependence or it may imply a contribution from ozone at the highest latitudes. The band asymmetry remains more compatible with that seen in a condensed form rather than a high-pressure gas, although the

## OXYGEN AND OZONE ON GANYMEDE: Calvin and Spencer

broadening of the absorption observed on Ganymede is probably related to the "warm" temperatures.

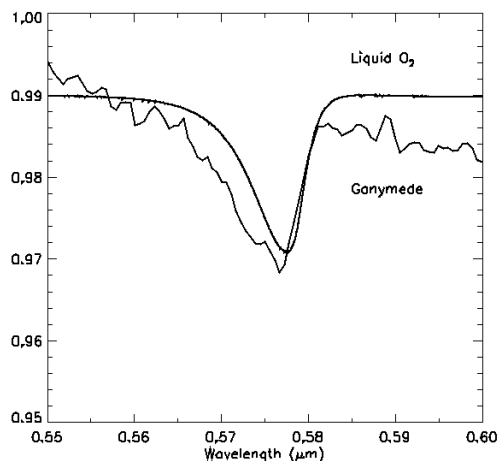


Figure 2. Hemispherically averaged spectrum from Spencer et al. [2] compared with a scaled transmission spectrum of liquid oxygen [12].

### Effects of Ozone

In addition to the strong ultraviolet absorption which was used to identify  $O_3$  on Ganymede [3,9], ozone also exhibits features in the visible [13], though these are an order of magnitude weaker than the uv features. The visible  $O_3$  features are much broader and shifted to longer wavelengths than the oxygen features. It could be expected that  $O_3$  might contribute to the observed spectral signature, particularly at higher latitudes. Vaida et al. [14] present spectra of ozone in an oxygen matrix, and the visible absorption feature is a distorted combination of  $O_2$  and  $O_3$ . This may contribute somewhat to the possible central shifts seen in our latitudinally resolved spectra; however,  $O_3$  exhibits an additional feature at  $0.6\mu m$ , which is not observed in the HST spectra.

### Some Ideas:

It appears that  $O_3$  is readily photolyzed at the equator resulting in the dominant spectral signature of  $O_2$  there. It may be that the polar shroud consists in part of  $O_3$ , and the polar ozone may contribute to the observed polar oxygen

emission. We have HST Cycle 7 time with STIS which may help resolve these issues.

Some work has been done regarding  $O_2/O_3/H_2O$  systems with respect to polar aerosols and the annual destruction of terrestrial ozone [15]. Other materials that are expected to be either intermediate or end products of photochemical processes include  $HO_2$  and  $H_2O_2$ . In particular,  $H_2O_2$  has found to be stable in Antarctic ice cores for as long as several thousand years [16]. While these peroxides have no visible absorption features, and apparently only weak absorption in the uv, at least  $H_2O_2$  is distinguished from water ice in the spectral range longer than  $3\mu m$  by strong features near  $3.08$  and  $3.571\mu m$  [17]. Calvin et al. [18] noted possible absorptions on the trailing hemisphere of Ganymede near  $3.5$  and  $3.6\mu m$  but were unwilling to interpret these without subsequent confirmation. Also of particular interest is the terrestrial finding that  $H_2O_2$  is primarily responsible for oxidation of  $SO_2$  in a liquid state and the generation of sulfuric acid [19,20]. On Ganymede it may be possible that similar mechanisms operate and result in the formation of sulfate-bearing minerals; this may help to explain the lack of pure  $SO_2$  on Ganymede. The data from Galileo NIMS should help in identifying other expected molecules.

**References** [1] Calvin and Spencer, BAAS, 26, p.1159, 1994. [2] Spencer et al., JGR, 100, p.19049, 1995. [3] Noll et al., Science, 273, p. 341, 1996. [4] Calvin et al., GRL, 23, p.673, 1996. [5] Johnson and Jessor, submitted, 1996. [6] Vidal et al., submitted, 1996. [7] Gurnett, et al., BAAS, 28, p. 1055, 1996. [8] Barth et al., EOS Suppl., 77, p. F430, 1996. [9] Hord et al., EOS Suppl., 77, p. F441, 1996. [10] Hall et al., BAAS, 28, p.1071, 1996. [11] Calvin and Spencer, submitted, 1997. [12] Calvin et al., BAAS, 27, p. 1165, 1995. [13] Inn and Tanaka, J. Opt. Soc. Am., 43, p. 870, 1953. [14] Vaida et al., J. Phys. Chem., 93, p. 506, 1989. [15] Sedlacek and Wight, J Phys. Chem., 93, p. 509, 1989. [16] Sigg and Neftel, Ann. Glaciol., 10, p. 157, 1988. [17] Lannon et al., J. Chem. Phys., 54, p.2212, 1971. [18] Calvin et al., JGR 100, p. 19041, 1996. [19] Penkett et al., Atmos. Env., 13, p. 123, 1979. [20] Calvert et al., Nature, 317, p. 27, 1985.